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Investigation of shear behavior of soil-concrete interface

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Abstract. The shear behavior of soil-concrete interface is mainly affected by the surface roughness of the two contact surfaces. The present research emphasizes on investigating the effect of roughness of soil-concrete interface on the interface shear behavior in two-layered laboratory testing samples. In these specially prepared samples, clay silt layer with density of 2027 kg/m^3 was selected to be in contact a concrete layer for simplifying the laboratory testing. The particle size testing and direct shear tests are performed to determine the appropriate particles sizes and their shear strength properties such as cohesion and friction angle. Then, the surface undulations in form of teeth are provided on the surfaces of both concrete and soil layers in different testing carried out on these mixed specimens. The soil–concrete samples are prepared in form of cubes of 10*10*30 cm. in dimension. The undulations (inter-surface roughness) are provided in form of one tooth or two teeth having angles 15° and 30°, respectively. Several direct shear tests were carried out under four different normal loads of 80, 150, 300 and 500 KPa with a constant displacement rate of 0.02 mm/min. These testing results show that the shear failure mechanism is affected by the tooth number, the roughness angle and the applied normal stress on the sample. The teeth are sheared from the base under low normal load while the oblique cracks may lead to a failure under a higher normal load. As the number of teeth increase the shear strength of the sample also increases. When the tooth roughness angle increases a wider portion of the tooth base will be failed which means the shear strength of the sample is increased.

Keywords: shear behavior; soil-concrete interface; failure pattern; shear strength

1. Introduction

The failure mechanism and fracture propagation and cracks coalescences in rocks and rock like materials have been extensively studied (both numerically and experimentally) considering the compressive, shear and tensile loading conditions (Fatehi Marji *et al*. 2007, Wu *et al*. 2010, Lancaster *et al.* 2013, Ramadoss 2013, Pan *et al*. 2014, Mobasher *et al*. 2014, Noel and Soudki 2014, Oliveira and Leonel 2014, Haeri *et al*. 2014, Kim and Taha 2014, Tiang *et al*. 2015, Wan Ibrahim *et al*. 2015, Silva *et al.* 2015, Gerges *et al.* 2015, Liu *et al*. 2015, Wasantha *et al.* 2015, Kequan and Zhoudao 2015, Lee and Chang 2015, Fan *et al*. 2016, Li *et al.* 2015, 2016, Sardemir 2016, Sarfarazi *et al.* 2016, Shuraim 2016, Akbas 2016, Rajabi 2016, Yaylac 2016, Mohammad 2016, Wang *et al*. 2016, 2017). Also, the shear behavior of the interfaces between a soil layer and a layer of different construction material have been investigated the researches because of its great importance in the design of concrete structures. They found that the interface shear strength may depends on various aspects of the two contacting layers such as their relative densities, surface roughness, applied normal stress, dilation angle, particle diameter (particle size) and moisture content of the soil layer (Potyondy 1961, Kulhawy and Peterson 1979, Desai *et al.* 1985, Rao *et al*. 2000, Chu and Yin 2006).

Sand-concrete interface under cyclic loading conditions are being studied through direct shear testing approach by Desai *et al.* (1985). Large direct shearing test was used by Yin (1995) to consider the shear stress distribution along the interface shear plane of soil and concrete. The direct shearing test approach was extended by Evgin *et al*. (1996) to investigate the direction changes of the soil-concrete interfaces. A combination of direct shear and microscopically tests were used by Hu *et al.* (2004) to show the sand particles movement paths. The simple shear testing approach was used by many researchers to study the interfaces of soil structures with different materials (e.g., Uesugi 1986a, b, 1988, 1990). These investigations were developed by Uesuge *et al*. (1986a) and used in the series of studies followed to investigate interfaces of different soil construction materials. The coefficient of friction between normally consolidated clay and steel plate was measured by Tsubakhara *et al*. (1993) using the direct shear testing apparatus in a soil mechanics laboratory. On the other hand, Wang *et al.* (2007) investigated the properties of the interface planes between clay of different water contents with that of concrete by considering the concrete surface toughness concept. The mechanical properties of the soil-

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concrete interface using the direct shear test under high stress conditions were measured by Zhue *et al.* (2007). A cyclic shear testing apparatus developed by Zhang et al (2006) to study the interfaces within the soil structures under cyclic loading conditions. They studied the interfaces between sand and steel and considered the soils particles movements during the shear test. The mechanical behavior of the interface between the soils of the core and filters in rock fill dams were studied by Zhang *et al.* (2008). They used a laminar-ring type shear testing apparatus and found that the interface shear strength is controlled by that of the weaker soil.

Various experimental techniques were used in the last decades for studying the soil–structure interface such as the strength and deformability characteristics, thickness, and constitutive material. Experimental studies using these techniques were performed essentially by means of direct shear boxes (Bacas 2015, Braja Das 2016, De Gennaro 2002, Ghazvinian 2012, Sarfarazi 2013, Ghionna 2002, Hammoud 2006, Hu 2004, Palmeira 2009, Peng *et al*. 2010, Shehata 2016, Zhang and Zhang 2009, Kavitha *et al*. 2016, Shahrour 1997, Tiwari 2010, Zeghal 2002), by means of pullout test apparatus (Esfandiari 2012, Ezzein 2014, Ferreira 2015, Horpibulsuk 2010, Zhang and Zhang 2003, Jayawickrama 2014, Li e*t al.* 2015, Khemissa 2004, Liu 2009, Park 2013, Rousé 2014, Suksiripattanpong 2013, Zhu *et al*. 2011, Frank 2017, Imani *et al.* 2017, Najigivi 2017, Khodayar and Nejati 2018, Nazerigivi *et al.* 2018, Kim *et al.* 2018). Miller and Hamid (2007) performed some interface tests between the unsaturated Minco silt and stainless steel. They showed that the interface shear strength increases with the increase of net normal stress. Sharma *et al.* (2007) carried out some laboratory tests on the specimens containing a soil geomembrane interface with provision for the measurement o pore pressures close to the interface during its shearing process. Hamid and Miller (2009) examined the shear behavior of the interface in between the unsaturated Minco silt and steel (smooth and rough surfaces). Hossain and Yin (2012) conducted a series of interface direct shear tests on the specimens made from completely compacted decomposed granite (CDG) soil and cement grout at both saturated and unsaturated conditions under different grouting pressures. A series of shear tests were performed on the soil-concrete interfaces using the independently developed visual large scale direct shear apparatus by Zhang and Zhang (2006, 2006). Gomez *et al.* (2008) investigated the effect of the unloading-reloading paths on the shear behavior at the sand-concrete interfaces by conducting a series of laboratory tests. Zhu *et al.* (2008), studied the shearing behavior at the interface of soil and concrete by accomplishing some shear tests on the specimens prepared from coarse-grained soil and concrete.

In the present work, some direct shear tests are conducted on the specially prepared specimens each containing an interface in between the two soil and concrete layers. The effects of surface roughness of the interface on the shear strength properties such as cohesion and friction angle are measured. The surface undulations in form of teeth are provided on the surfaces of both concrete and soil layers in different testing carried out on these mixed specimens. The soil–concrete samples are 10*10*30 cm. cubes prepared in a rock mechanics laboratory.

2. Direct shear test

The experimental work is carried out on the specially prepared two layered specimens from soil and concrete under direct shear testing condition with in the laboratory.

2.1 Determination of shear properties of soil sample

The direct shear testing is performed on the soil samples to determine shear properties of the soil samples. Four types of normal loading (i.e., 80, 150, 300 and 500 KPa) are used to accomplish these tests in the laboratory. The soil’s cohesion and friction angle are measured from these laboratory tests and tabulated in Table 1.

2.2 The procedure and specifications for specimen casting

The shear behavior of soil and concrete teeth at the interface of the specimen is studied by assuming two roughness angles 15° and 30°, in this paper. These roughness angles are numbered as 1 and 2 in Fig. 1. This figure shows the specific plates used for creating teeth in the interface of the casted specimen.

(a)

(b)

Fig. 1 (a) Plates with different roughness and (b) the machine used for creation of tooth on the plate

Fig. 2 The mold used for sample preparation

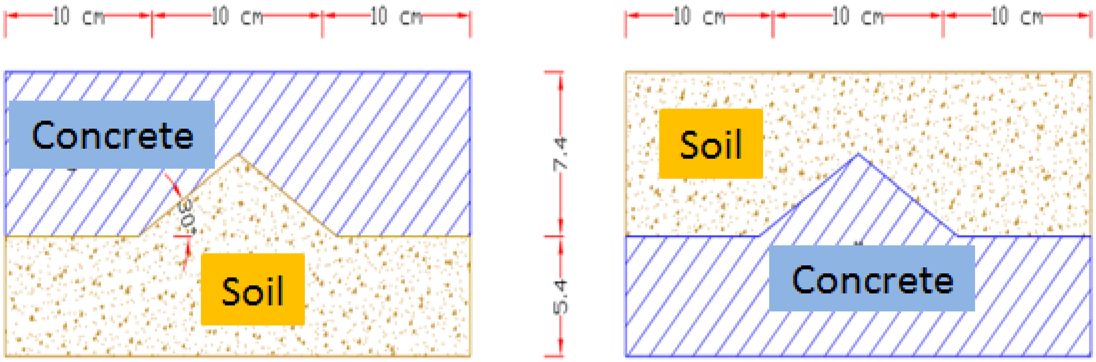


Fig. 3 One tooth with angularity of 30°.

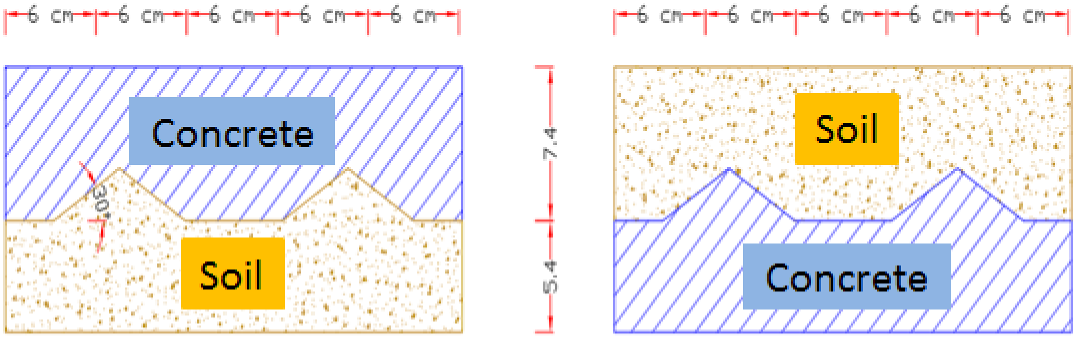


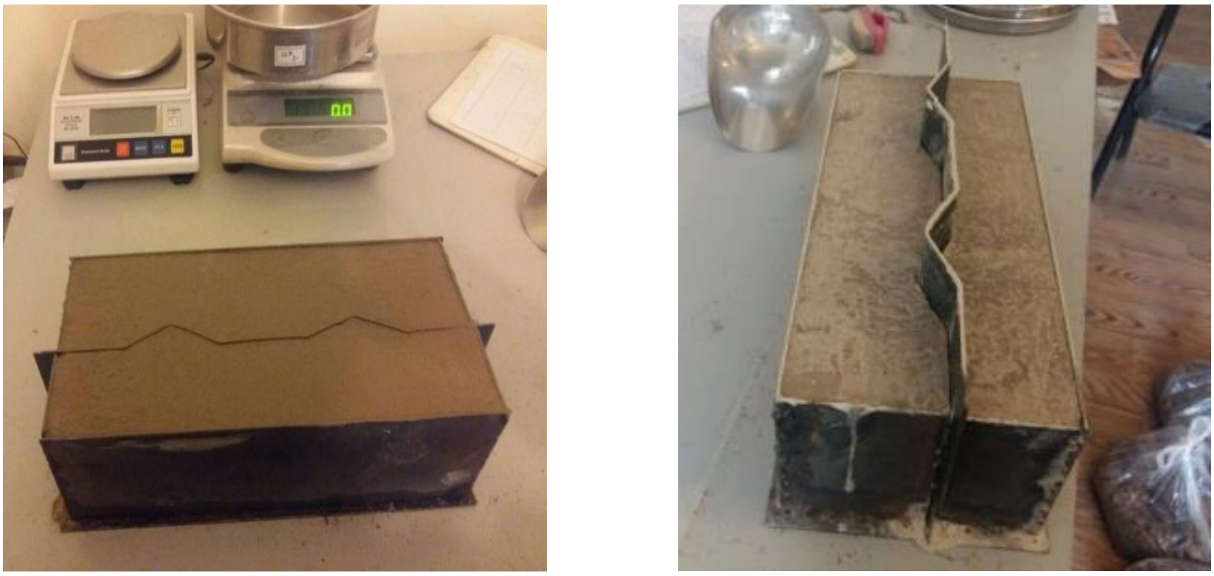
Fig. 4 Two teeth with angularity of 30°

Table 1 The results of direct shear test

parameter	unit	value
cohesion	KPa	95
Friction angle	°	17

The casted plates with the desired roughness are prepared for this reason these plates are inserted inside the main mold through the notches situated in the two sided of the mold (as shown in Fig. 2).

The number of tooth in concrete and soil is 1 and 2 (Figs. 3 and 4). The angel of roughness is 15° and 30° (Fig. 3). The concrete and soil specimens are casted inside the mold as shown in Fig. 5. These two casted parts of the combined concrete-soil specimens are shown in Fig. 6. Direct shear test were performed under normal stresses of 80 MPa, 150 MPa, 300 MPa and 500 MPa. Concrete sample is situated in the lower box and soil sample is situated in the upper box while conducting the tests in the laboratory. All teats are performed under strain control with a constant velocity of 0.01 mm/min (Fig. 7).



(a) (b)

Fig. 5 (a) soil specimen and (b) concrete specimen

Fig. 6 The concrete specimen

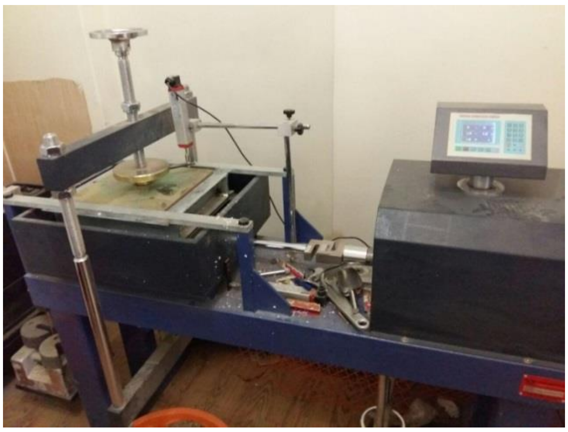


Fig. 7 Direct shear test apparatus

3. Direct shear tests performed on the soil-concrete interface

The effect of concrete and soil teeth and also the influence of normal stress on the shearing behaviour of soil-concrete interfaces (failure pattern and shear strength) have been investigated in this section.

3.1 Effects of soil-concrete interface and tensile load on the failure pattern of specimens

a) Number of soil tooth is 1 and its angularity is 15° under normal stress of 80 KPa: in this configuration the soil tooth was sheared from the base and shear failure was occurred (Fig. 8).
b) Number of soil tooth is 2 and its angularity is 15° under normal stress of 80 KPa: in this configuration, two soil teeth was sheared from the base and one orientated crack lead to separation of soil specimen from the concrete sample (Fig. 9).
c) Number of soil tooth is 1 and its angularity is 30° under normal stress of 80 KPa: in this configuration, the soil-concrete interface was separated and three vertical crack were occurred in the soil sample (Fig. 10).
d) Number of soil tooth is 2 and its angularity is 30° under normal stress of 80 KPa: in this configuration, two soil teeth was sheared from the base and one vertical crack lead to separation of soil sample from concrete specimen (Fig. 11).
e) Number of concrete tooth is 1 and its angularity is 15° under normal stress of 150 KPa: in this configuration, the soil-concrete interface was separated and one vertical crack lead to separation of soil sample from concrete specimen (Fig. 12).
f) Number of concrete tooth is 1 and its angularity is 15° under normal stress of 300 KPa: in this configuration, the soil-concrete interface was separated (Fig. 13).
g) Number of concrete tooth is 2 and its angularity is 15° under normal stress of 150 KPa: in this configuration, the soil-concrete interface was separated and one vertical crack lead to separation of soil sample from concrete specimen (Fig. 14).
h) Number of concrete tooth is 2 and its angularity is 15° under normal stress of 300 KPa: in this configuration, the soil edge was sheared and one oriented crack lead to separation of soil sample from concrete specimen (Fig. 15).
i) Number of concrete tooth is 2 and its angularity is 15° under normal stress of 150 KPa: in this configuration, one oriented crack lead to separation of soil sample from concrete specimen (Fig. 16).
j) Number of concrete tooth is 2 and its angularity is 30° under normal stress of 300 KPa: in this configuration, the soil edge was sheared and one oriented crack lead to separation of soil sample from concrete specimen (Fig. 17).
k) Number of concrete tooth is 2 and its angularity is 30° under normal stress of 500 KPa: in this configuration, the soil edge was sheared and one oriented crack lead to separation of soil sample from concrete specimen (Fig. 18).

Fig. 8 Number of soil tooth is 1 and its angularity is 15° under normal stress of 80 KPa

Fig. 9 Number of soil tooth is 2 and its angularity is 15° under normal stress of 80 KPa

Fig. 10 Number of soil tooth is 1 and its angularity is 30° under normal stress of 80 KPa

Fig. 11 Number of soil tooth is 2 and its angularity is 30° under normal stress of 80 KPa

Fig. 12 Number of concrete tooth is 1 and its angularity is 15° under normal stress of 150 KPa

Fig. 13 Number of concrete tooth is 1 and its angularity is 15° under normal stress of 300 KPa

Fig. 14 Number of concrete tooth is 2 and its angularity is 15° under normal stress of 150 KPa

Fig. 15 Number of concrete tooth is 2 and its angularity is 15° under normal stress of 300 KPa

Fig. 16 Number of concrete tooth is 2 and its angularity is 15° under normal stress of 150 KPa

Fig. 17 Number of concrete tooth is 2 and its angularity is 30° under normal stress of 300 KPa

Fig. 18 Number of concrete tooth is 2 and its angularity is 30° under normal stress of 500 KPa

3.2 Effects of concrete-soil interface and normal stress on the shear strength of the specimens

Fig. 19 shows the variation of shear strength versus number of soil tooth for tooth angularity of 15° and 30° under normal stress of 80 KPa. Totally the shear strength decreases by increasing the tooth number. Also the shear strength was increased by increasing the tooth angel from 15° to 30 °.

Fig. 20 shows the variation of shear strength versus normal stress for different configuration of concrete tooth i.e., one concrete tooth with angularity of 15°, two concrete tooth with angularity of 15° and two concrete tooth with angularity of 30°. Totally the shear strength increases by increasing the normal stress. Also two tooth with angularity of 30° has maximum strength value while two tooth with angularity of 15° has minimum strength value.

Shakir *et al.* (2010) studied the mechanical interaction of drilling slurries at the soil-concrete contact (Fig. 21).

The results shows that Using bentonite slurry as an interface layer (1–2 mm) between clay and concrete reduces the interfacial shear strength by 23% and using bentonite slurry as an interface layer (1–2 mm) between sandy clay and concrete increases the interfacial shear strength by 10%.

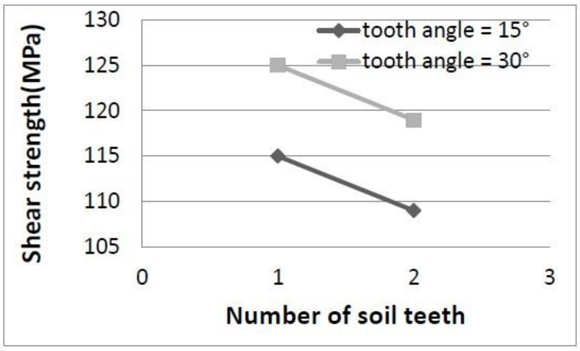


Fig. 19 the variation of shear strength versus number of soil tooth for tooth angularity of 15° and 30° under normal stress of 80 KPa

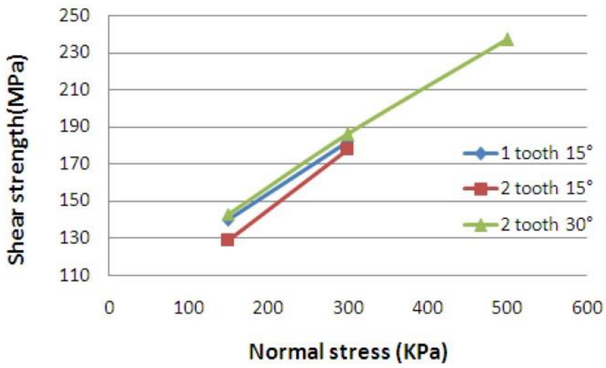


Fig. 20 the variation of shear strength versus normal stress for different configuration of concrete tooth i.e. one concrete tooth with angularity of 15°, two concrete tooth with angularity of 15° and two concrete tooth with angularity of 30°

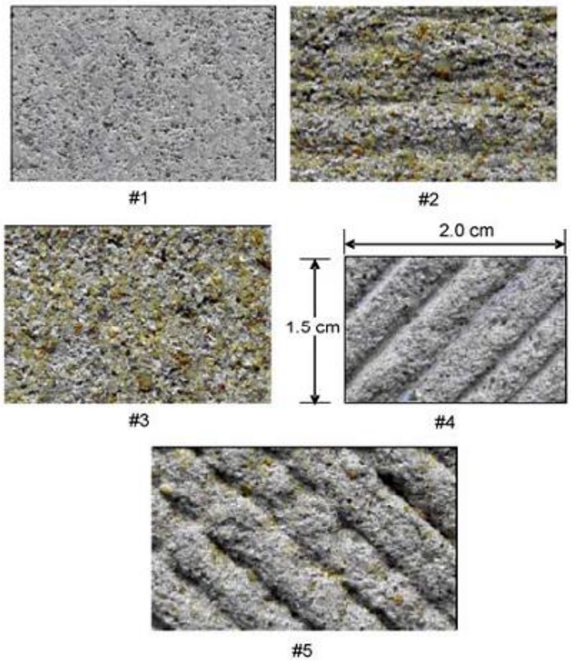


Fig. 21 Concrete surface shapes

Also using polymer slurry as an interface layer between clay and concrete decreases the interfacial shear strength by 17% and using polymer as an in-terface layer between sandy clay and concrete in-creases the interfacial shear strength by 10%. Using bentonite and polymer slurry as an interface layer between clay and concrete decreases the sliding ratio by 50%–60% while increasing the sliding ratio to 44%–56% when used as an interface layer between sandy clay and concrete. The failure mechanism in this study was similar to shakir investigation (2010).

4. Conclusions

The effect of roughness of a soil-concrete interface on the shearing behavior of this interface is investigated in the present paper. The soil surface of the soil part of a mixed specimen is made of a clayey silty soil with a density of 2027 kg/m^3. The dimension of each soil –concrete specimen is 10*10*30 cm which contains either one tooth or two teeth each may have angles 15° and 30°. The direct shear tests are performed on these different samples under different normal load by applying a constant displacement rate of 0.02 mm/min. The results obtained from these testing operation in the laboratory may be categorized as:

- The teeth number, roughness angle and applied normal stress may all effect on the fracture pattern and failure process starting from the base part of the specimen under low normal loading condition while the oriented cracks may lead to a shear failure under high normal loading condition. The less volume of teeth are mobilized in .the process of shearing failure as the teeth number is increased at the interface. Also, the wider base may be failed easier as the teeth roughness angle is increasing.
- At a constant normal loading condition the interface shear strength is decreased with increasing the teeth number. Also, this shear strength may be increased by increasing the teeth roughness angle from 15° to 30°.
- The overall interface shear strength is increased with increasing the normal stress.
- A two teeth interface with an angularity of 30° has the maximum value of interface shear strength while a two teeth interface with an angularity of 15° has the minimum value of the shear strength.

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